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Mesoscale and Microscale Meteorology

# Satellite Data Assimilation in WRF-Var

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**Collaborations… but no support :-(**

# Outline

Basic concepts of satellite data assimilation

Satellite DA in WRF-Var + impact studies

Practical issues: current status on satellite work

Conclusions

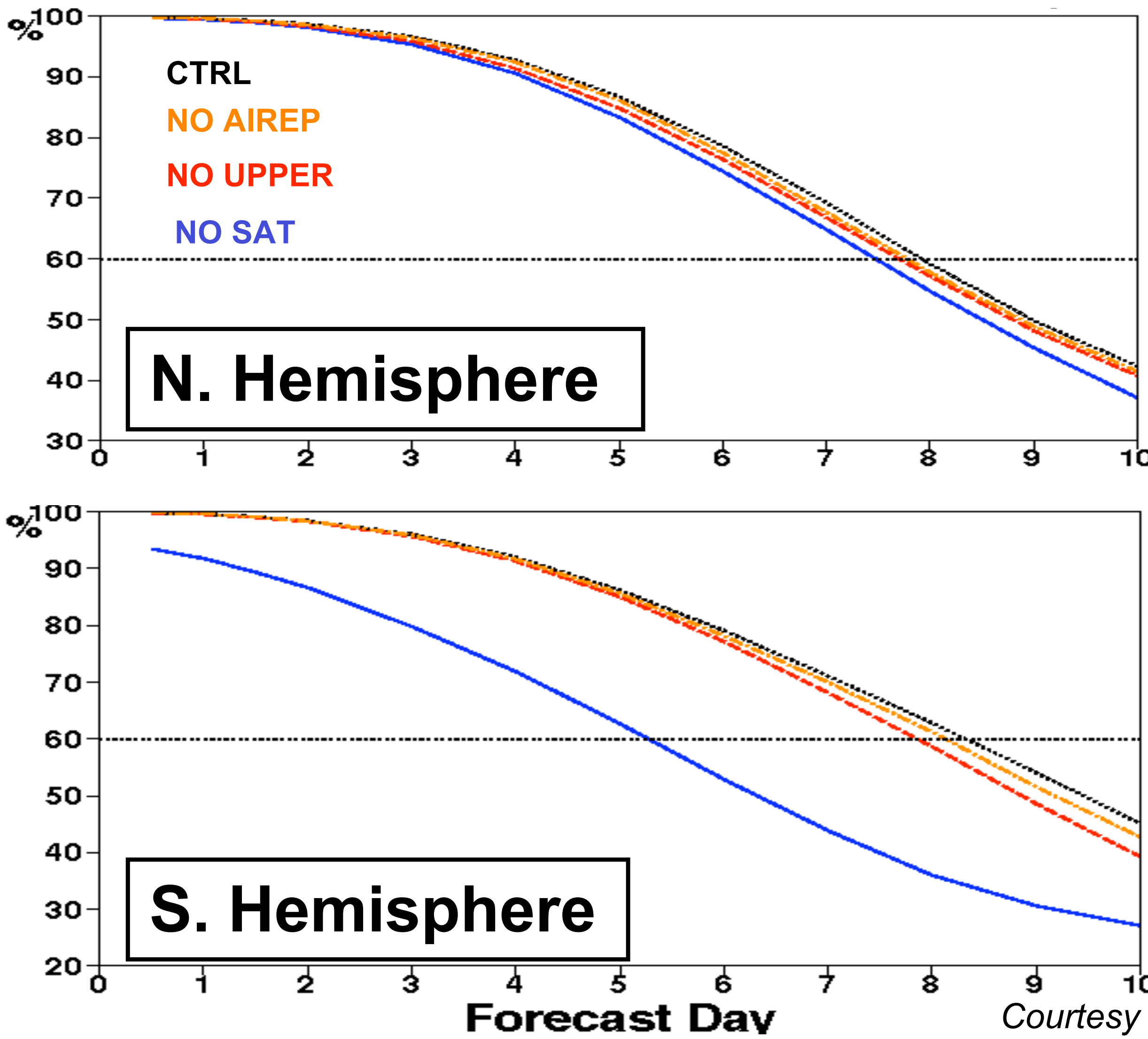
# Basic Concepts

## Why should I care about satellites?

# Basic Concepts: Satellite Impact

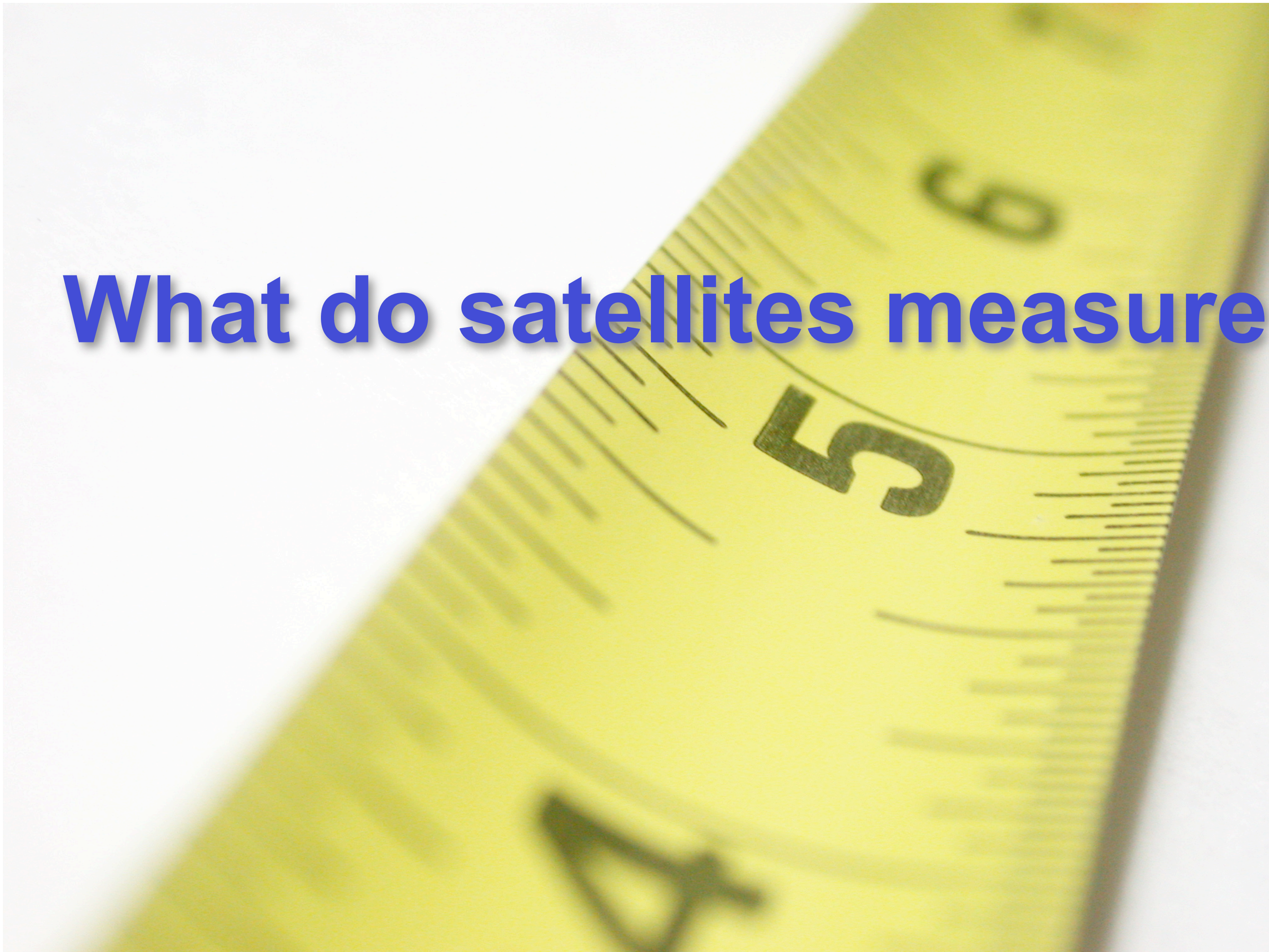
*Satellites = main source of information within observing network for NWP*

**4-month Observing System Experiments (OSEs)**




*Courtesy ECMWF*

# Basic Concepts



## What do satellites measure?

# Basic Concepts: Satellites measure…

- ♠ Temperature / Humidity / Ozone profiles

- ♥ Surface Temperature / Emissivity / Albedo

- ♦ Wind

- ♣ Radiance / Radio Signal

# Basic Concepts: Radiative Transfer

$$L(\nu) = \int_0^\infty B(\nu, T(z)) \left[ \frac{d\tau(\nu)}{dz} \right] dz + \text{Surface} + \text{Cloud/rain}$$

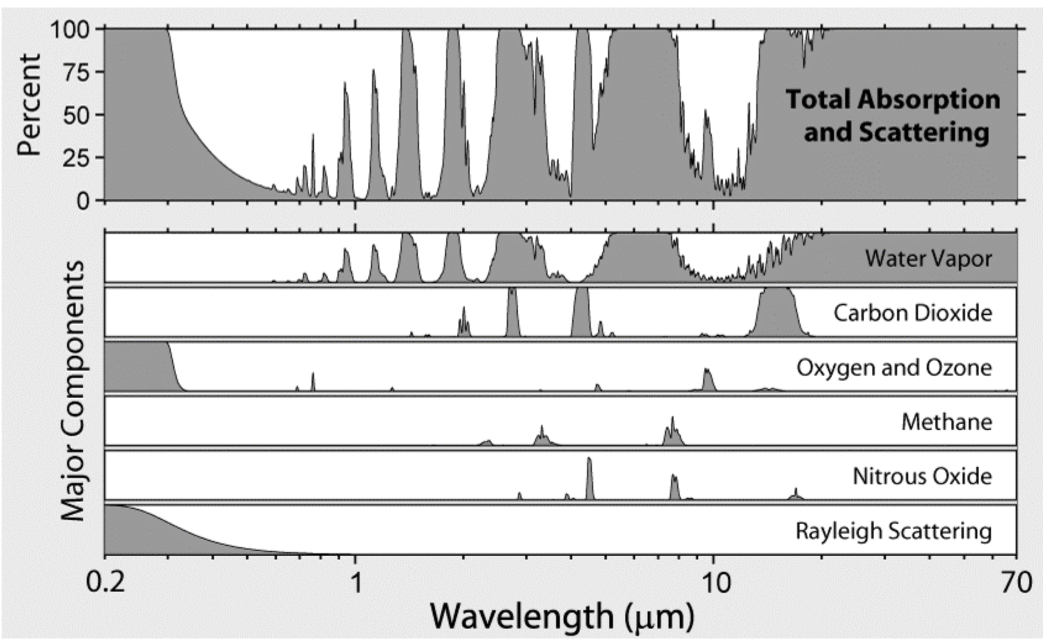
TOA radiance at frequency n

Planck function

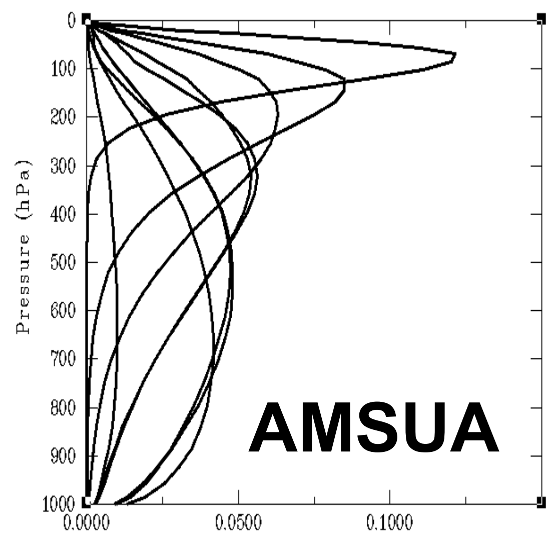
Atmospheric absorption

Emission/reflection

Diffusion/scattering




- Temperature information derived from well-mixed absorbents (CO2, …)
- Channels sensitive to Humidity, Ozone, …
- Surface channels: "window" parts of spectrum



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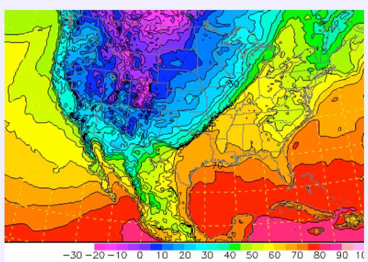
CRTM, RTTOV, …

T, Q, O3, …

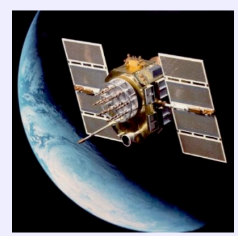
Forward model

L(n)

RT




Inversion



Regression, neural network, 1D-Var

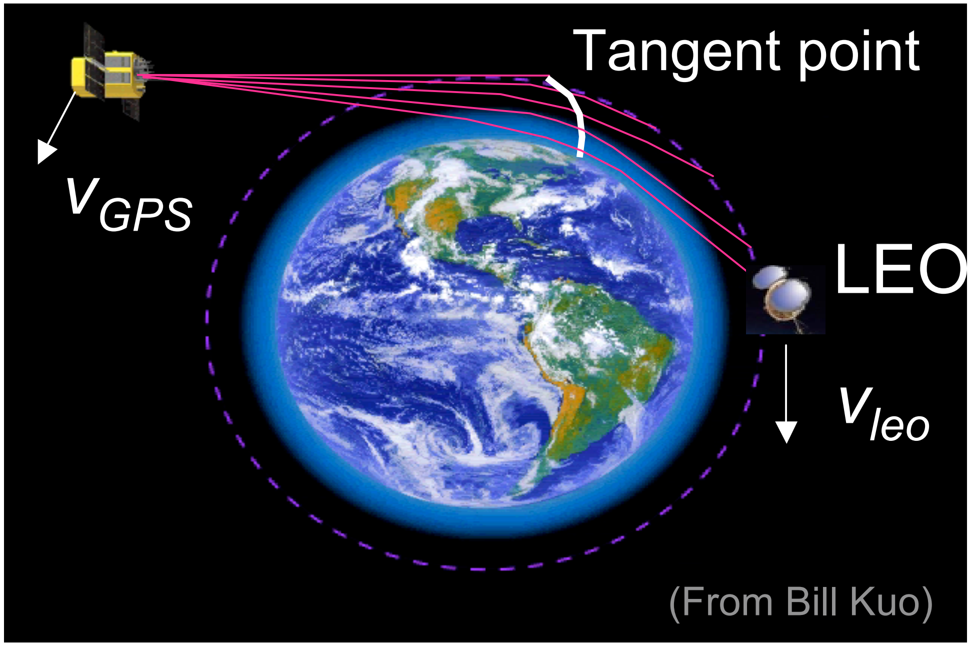
# Basic Concepts: GPS Radio Occultation

The ray path of a transmitted radio signal during an occultation is bent due to the atmospheric refraction related to the atmospheric state (T, p and q) in neutral atmosphere.

**Constellation Observing System for Meteorology, Ionosphere & Climate** (COSMIC)

Features of measurements

- high vertical resolution
- all-weather
- unbiased
- coarse horizontal resolution
- multi-path problem in lower levels



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# Satellite DA: WRF-Var capabilities

- **Retrievals (T / Q profiles)**
  - SATEM (from AMSU)
  - AIRS retrievals (NASA version 5)
- **GPS Radio Occultation**
  - Retrieved refractivity from COSMIC
- **Winds**
  - Retrieved winds: polar MODIS, SATOB
  - Active sensors: Quikscat
- **Radiances** (BUFR format from NCEP/NRL/AFWA/NESDIS)
  - **HIRS** from NOAA16, 17, 18
  - **AMSU-A** from NOAA15, 16, 18, EOS-Aqua, METOP-2
  - **AMSU-B** from NOAA15, 16, 17
  - **MHS** from NOAA18, METOP-2
  - **AIRS** from EOS-Aqua
  - **SSMIS** from DMSP16

# Satellite DA: WRF-Var capabilities

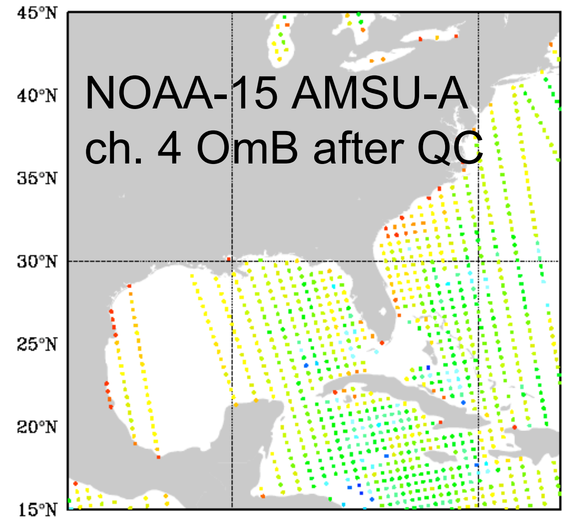
- **Radiative Transfer Model**

**CRTM (Community Radiative Transfer Model)**
JCSDA (Joint Center for Satellite Data Assimilation)
*ftp://ftp.emc.ncep.noaa.gov/jcsda/CRTM/*
Latest released version: CRTM REL-1.2_beta, September 2008
Version used in WRF-Var: CRTM REL-1.1
Documentation still under development

**RTTOV (Radiative Transfer for TOVS)**
EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites)
*http://www.metoffice.gov.uk/research/interproj/nwpsaf/rtm/index.html*
Latest released version: RTTOV_9_2, July 2008
Version used in WRF-Var: RTTOV_8_7 (with a small bug fix)

- **Radiance monitoring tools**

# Case Study: Hurricane Katrina

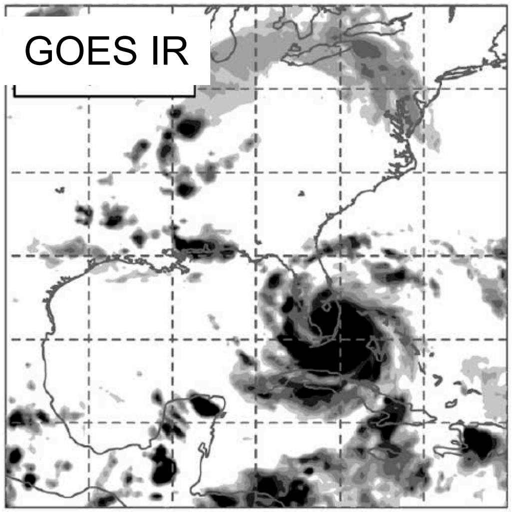



12km51L, model top 10mb

RTTOV Radiative Transfer Model

AMSU-A assimilated
Ch. 1~4 over sea
Ch. 5~10 both over sea and land

Pixels over precipitating area rejected



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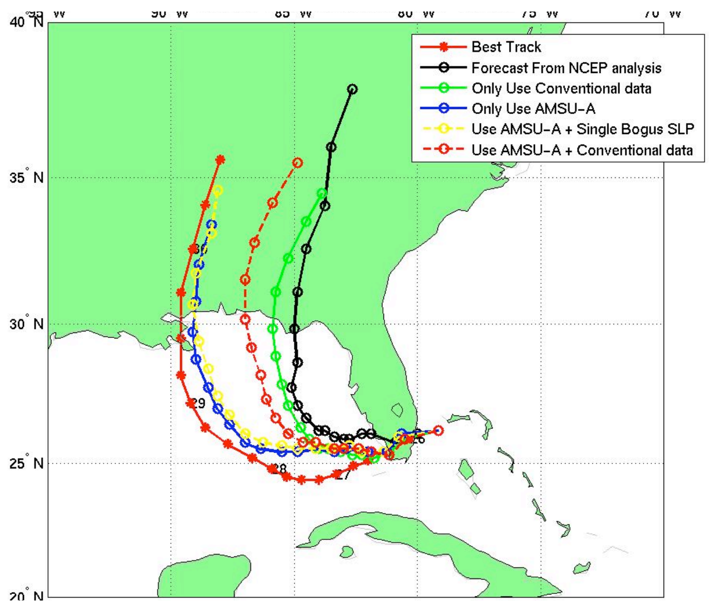
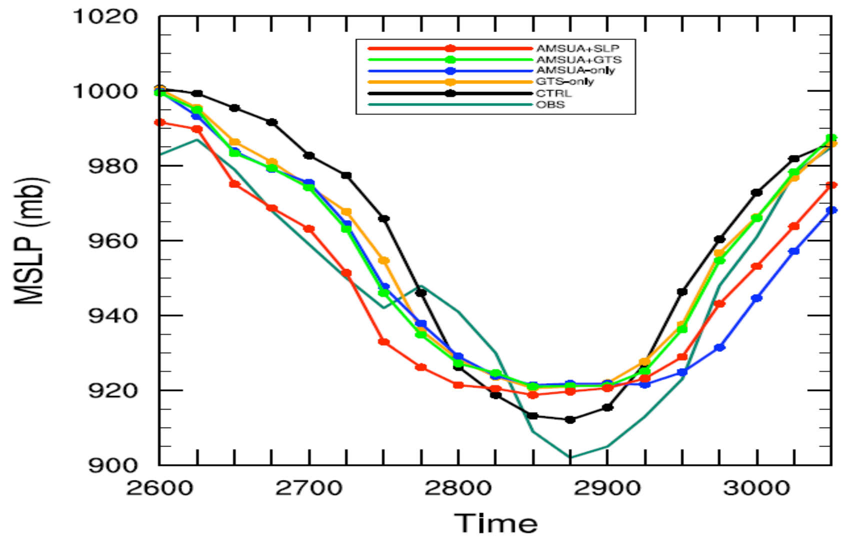
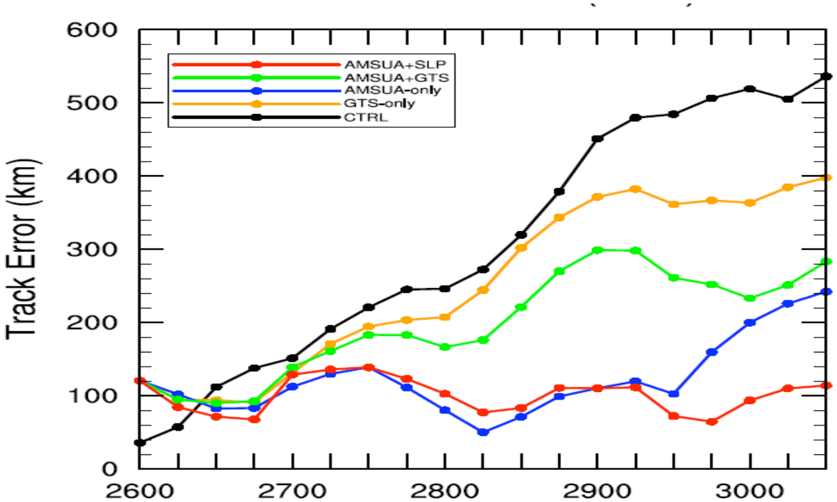
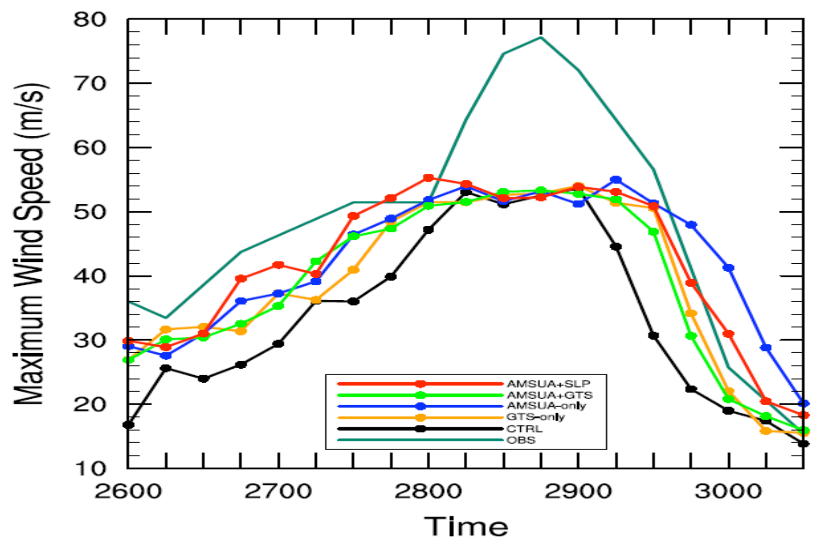


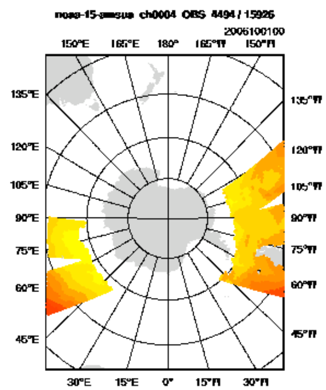



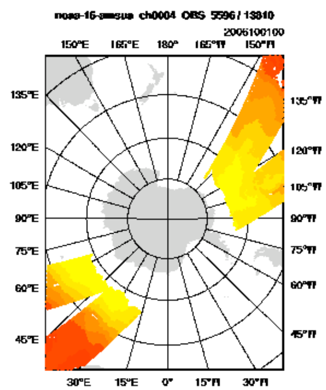



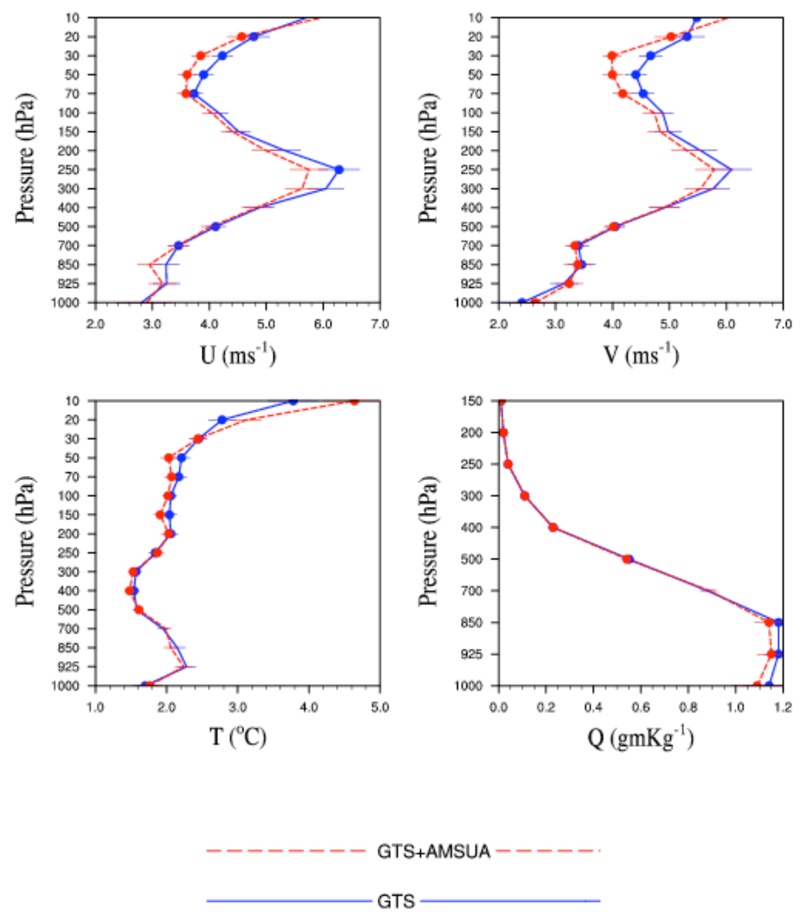
# Impact study: Antarctic Region

- 60km horizontal resolution
- 57 vertical levels, model top = 10mb
- Full cycling expt for 14 days
  (1 ~ 14 October 2006)
- NOAA 15/16/18 AMSUA ch. 4~9





**RMSE: 36h forecast *vs.* Radiosondes**



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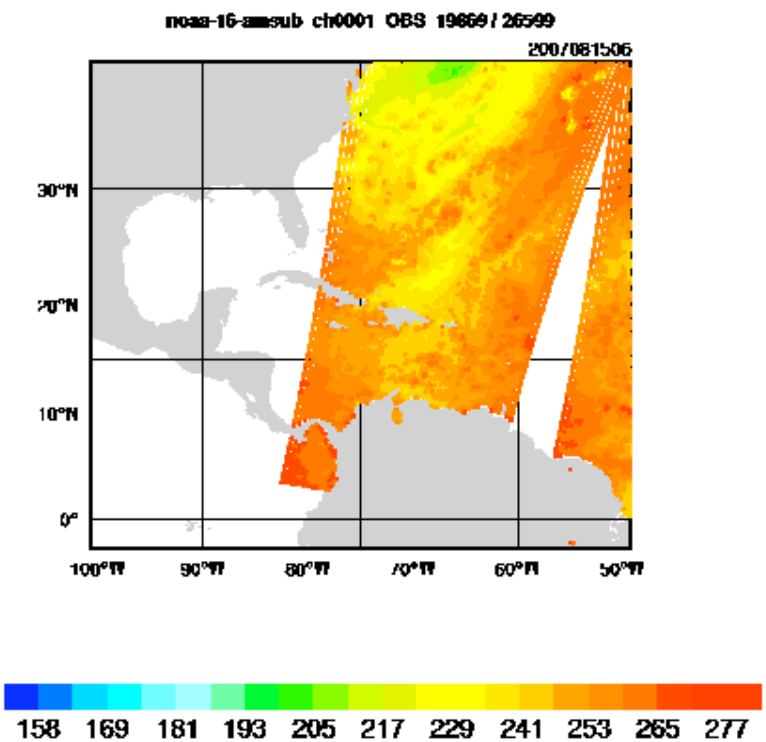
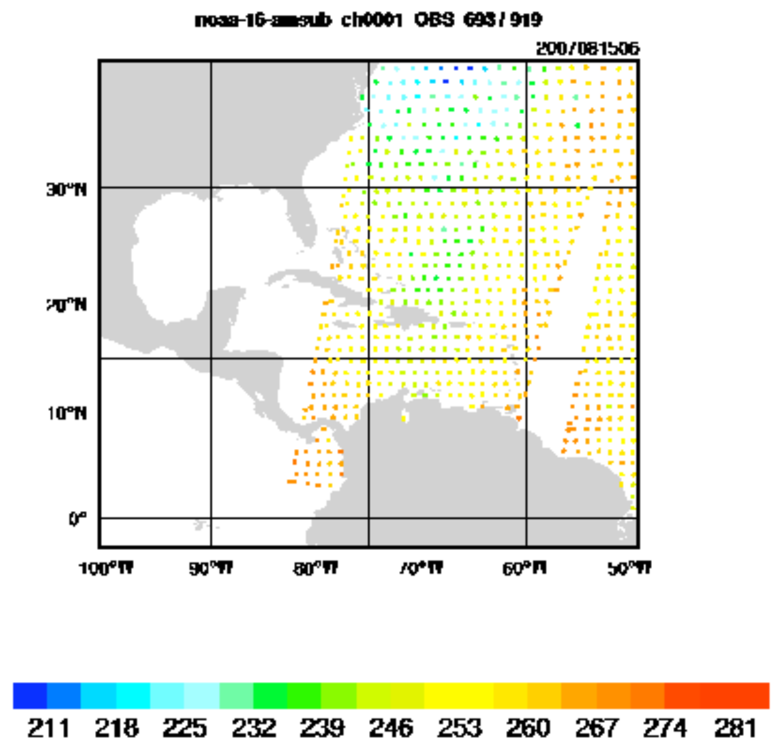
# Practical issues: Thinning

No Thinning




120km Thinning Mesh



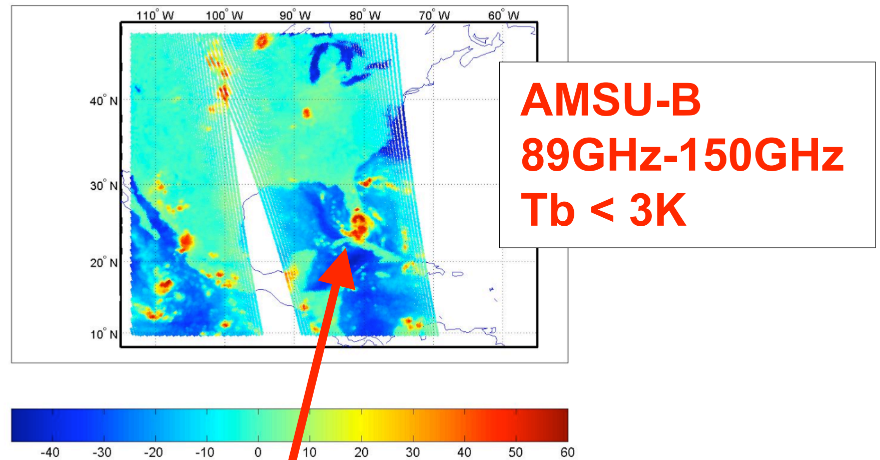
# Practical issues: Quality Control

- **Specific QC for each sensor**
  AMSU-A, AMSU-B, MHS, SSMIS, AIRS

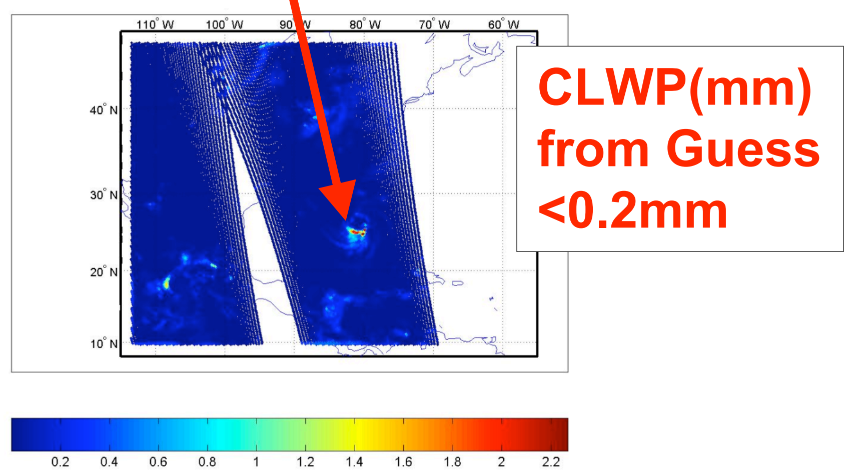
- **Pixel-level QC**
  - Reject **limb** observations
  - Reject pixels over **land** and **sea-ice**
  - **Cloud/Precipitation** detection
  - **Synergy** with imager (AIRS/VIS-NIR)

- **Channel-level QC**
  - **Gross check** (innovations <15 K)
  - **First-guess check** (innovations < $3s_o$).

- **Observation error tuning**
  - Error factor tuned from objective method
    (Desrozier and Ivanov, 2001)




**Katrina Location** (2005/08/26/06Z)



# Practical issues: Bias Correction

Modeling of errors in satellite radiances:

$$y = H(x_t) + B(\beta) + \varepsilon$$

$$\begin{cases} \langle \varepsilon \rangle = 0 \\ B(\beta) = \sum_{i=1}^{N} \beta_i p_i \end{cases}$$

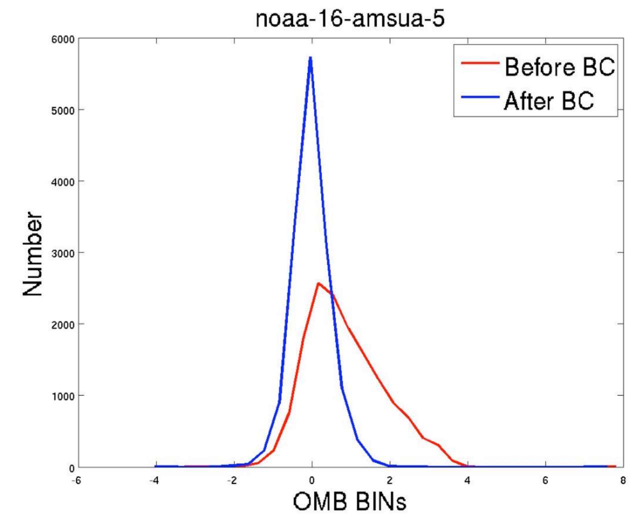
**Parameters**

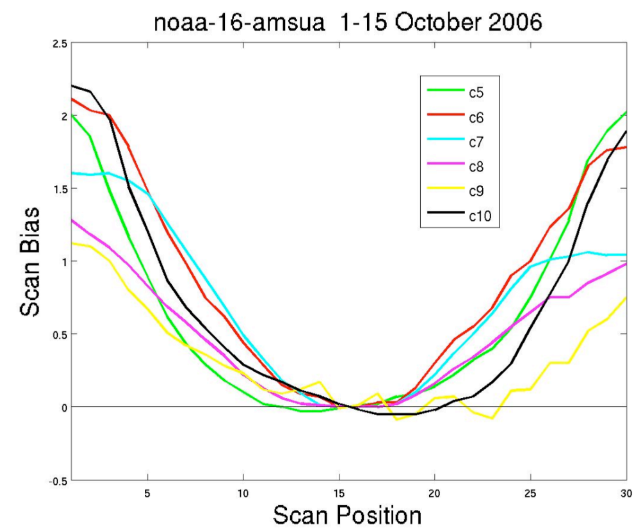
**Predictors**:

- Offset
- 1000-300mb thickness
- 200-50mb thickness
- Surface skin temperature
- Total column water vapor
- Scan

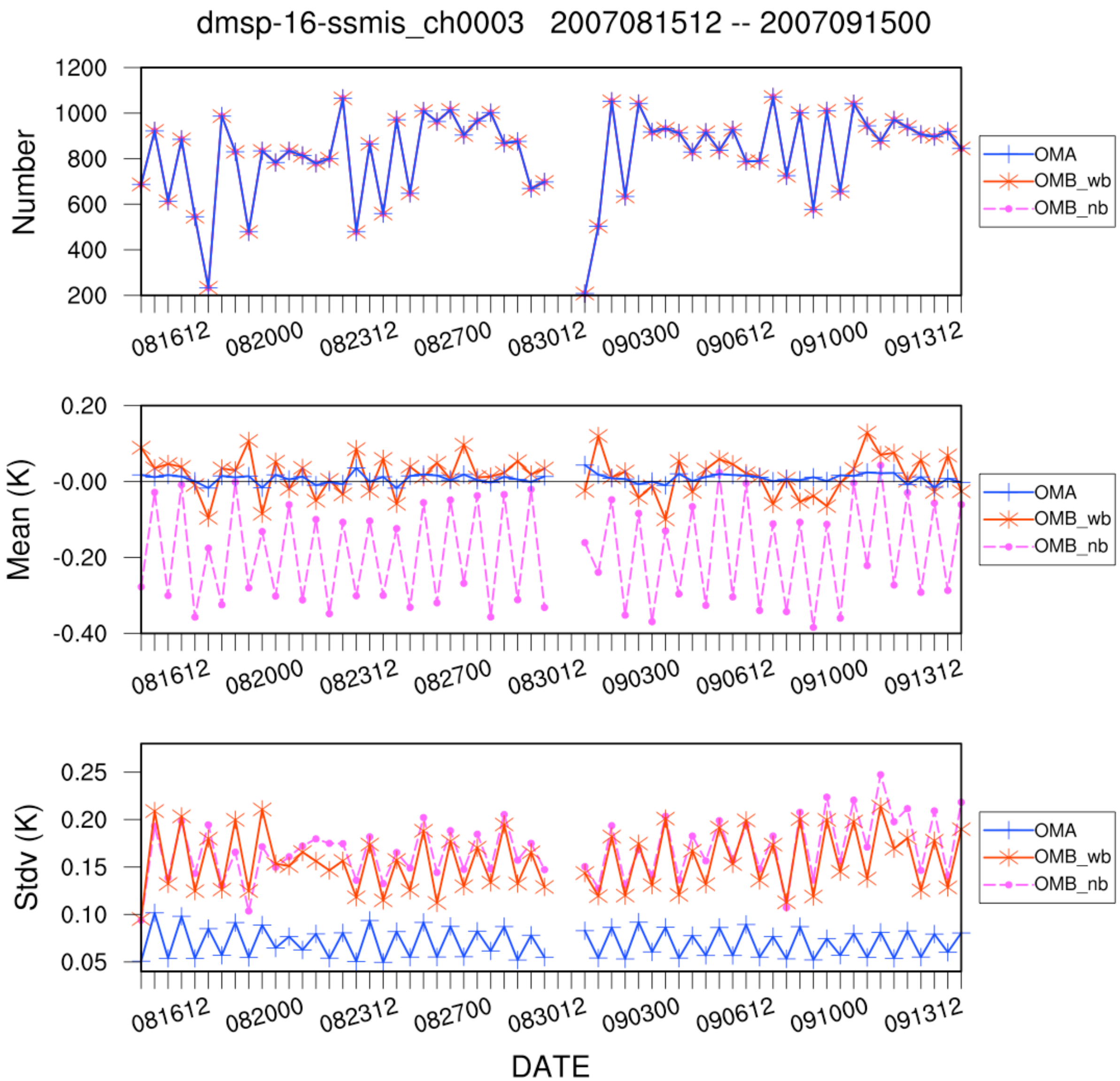
**"Offline" bias correction**

**"Variational" bias correction**



# Practical issues: Bias Correction

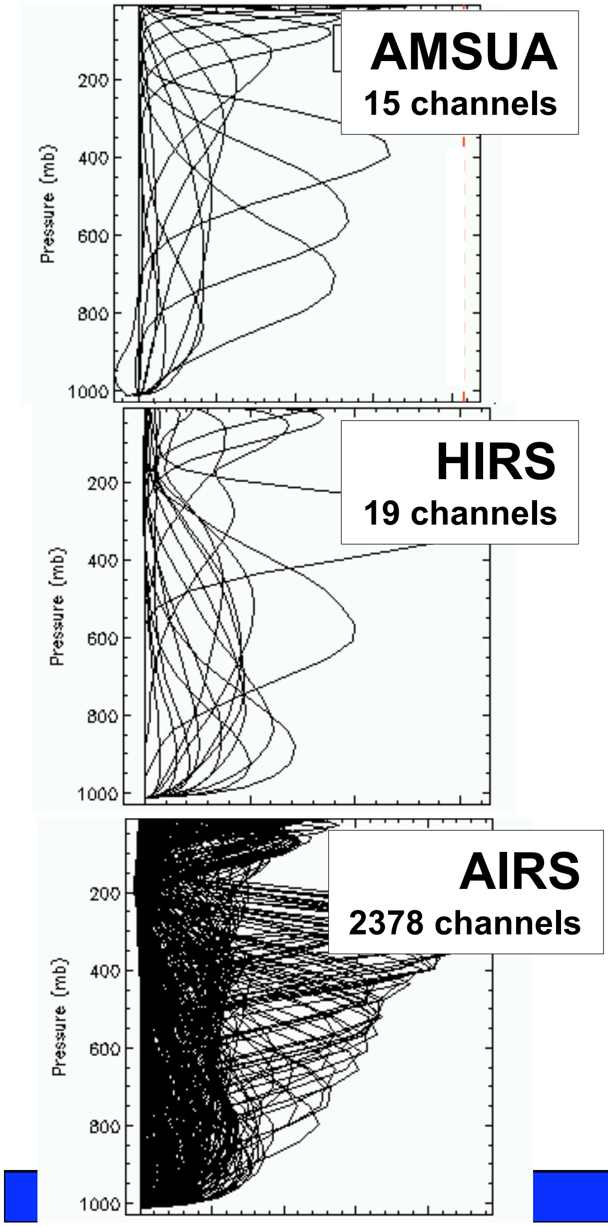



------ Observation minus Background BEFORE bias correction

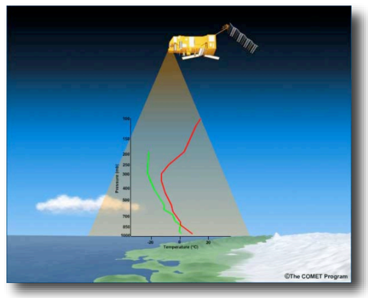
------ Observation minus Background AFTER bias correction

------ Observation minus Analysis

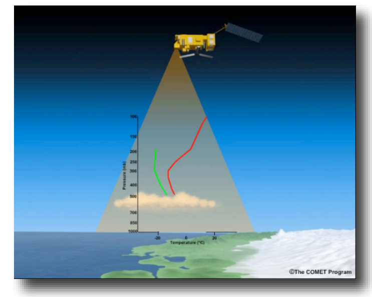
# Practical issues: AIRS Cloud Detection

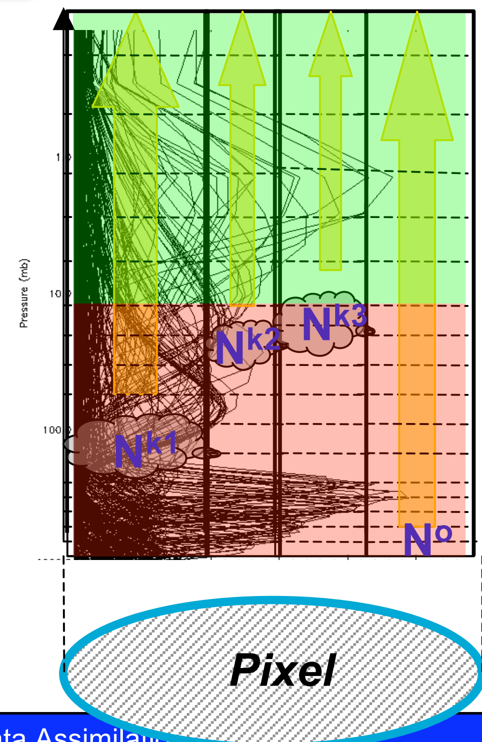



From « **hole hunting** »
(identifying clear pixels)…



… to **identifying clear channels**
(insensitive to the cloud).

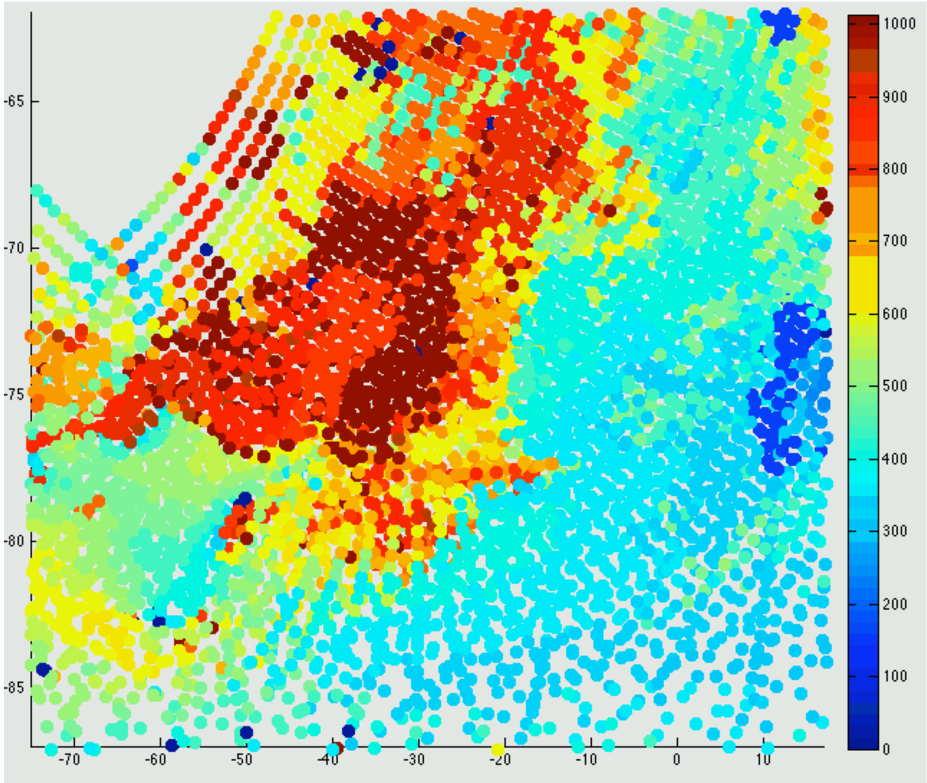




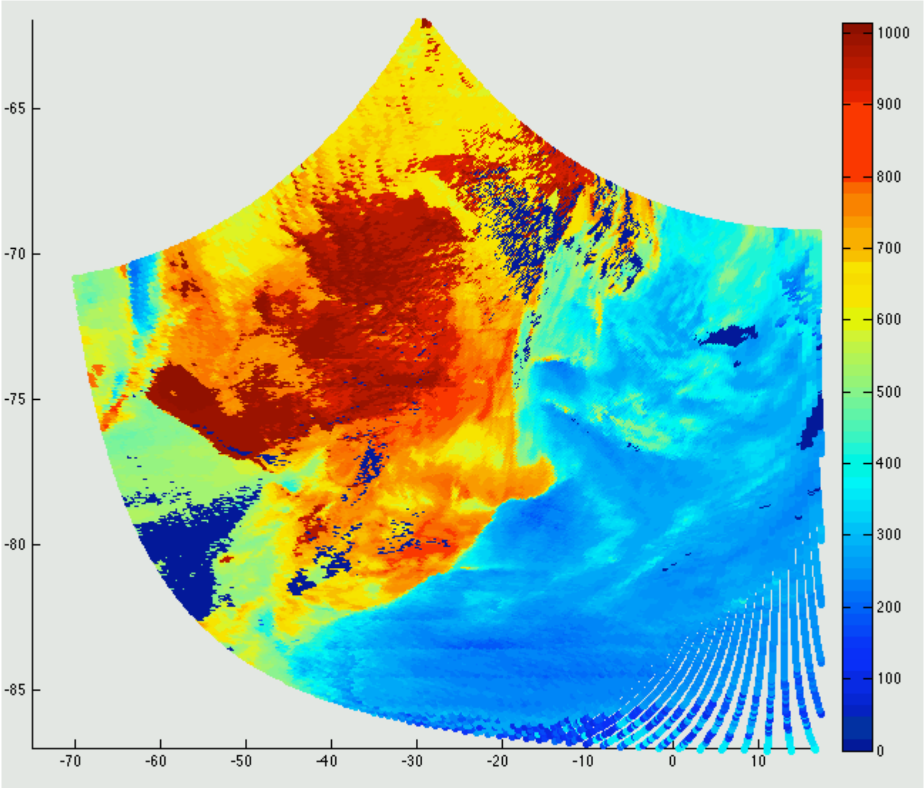

Cloud fractions $N^k$ are ajusted **variationally** to fit observations.

# Practical issues: AIRS Cloud Detection

AIRS Cloud Detection




MODIS NASA Level 2 Product




**Cloud Top Pressure (hPa)**

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# Conclusions

- **Satellite data are important**
  - Major source of information within observations for global NWP
  - Positive impact on Limited Area Models
- **Satellite assimilation is not trivial**
  - Very easy to degrade the analysis!
  - Each sensor requires a lot of attention (observation operator, bias correction, QC, observation error, cloud/rain detection, …)
- **It's only the beginning…**
  - New generation of satellite instruments
  - Future developments will increase satellite impact
    - Better representation of surface emissivity over land
    - Use of cloudy/rainy radiances
    - ……………………………………………………

# Conclusions: Steps for Collaboration

- **Get familiar with WRF-Var code**
  - Run test cases
  - Run your Control expt, assimilating conventional data
- **Plan your satellite experiments**
  - Sensors of interest for your application
  - Ways to get data and corresponding format
  - Potential code developments
- **Contact NCAR/MMM developers**
  - Zhiquan Liu: liuz@ucar.edu
  - Tom Auligné: auligne@ucar.edu
  - Hans Huang: huangx@ucar.edu